PID consortium: Proposal for an integrated program of particle identification challenges and opportunities for a future EIC

M. Alfred, M. Awadi, B. Azmoun, L. Allison, F. Barbosa, W. Brooks, T. Cao, M. Chiu, I. Choi, M. Contalbrigo, A. Datta, C.L. da Silva, M. Demarteau, J.M. Durham, R. Dzhygadlo, D. Fields, M. Grosse-Perdekamp, C. Han, J. Harris, X. He, H. van Hecke, T. Horn, J. Huang, C. Hyde, Y. Ilieva, G. Kalicy, E. Kistenev, Y. Kulinich, J. Lindesay, M. Liu, R. Majka, J. McKisson, R. Mendez, P. Nadel-Turonski, K. Park, K. Peters, R. Pisani, Yi Qiang, S. Rescia, P. Rossi, M. Sarsour, C. Schwarz, J. Schwiening, N. Smirnov, J. Stevens, A. Sukhanov, J. Toh, R. Towell, T. Tsang, Ji Wang, R. Wagner, C. Woody, W. Xi, J. Xie, L. Xue, N. Zachariou, Z. Zhao, B. Zihlmann, C. Zorn.

Outline

1. Introduction

2. Time-of-Flight (TOF)

3. RICH

4.1 DIRC

4.2 Sensors in high magnetic fields (DIRC)

5. Sensors: LAPPDs

6. Funding Request

Participating institutions

- Abilene Christian University (ACU)
- Argonne National Lab (ANL)
- Brookhaven National Lab (BNL)
- Catholic University of America (CUA)
- Duke University (Duke)
- Georgia State University (GSU)
- GSI Helmholtzzentrum für Schwerionenforschung, Germany (GSI)
- Howard University (HU)
- Istituto Nazionale di Fisica Nucleare, Italy (INFN)
- Jefferson Lab (JLab)
- Los Alamos National Lab (LANL)
- Old Dominion University (ODU)
- Universidad Técnica Federico Santa María, Chile (UTFSM)
- University of Illinois Urbana-Champaign (UIUC)
- University of New Mexico (UNM)
- University of South Carolina (USC)
- Yale University (Yale)

PID consortium

1. Goal: developing integrated PID solutions for EIC detector(s)

- Refining existing concepts: MEIC-IP1, ePHENIX, eSTAR, BeAST
- New ideas?

2. Initial focus on hadron ID, but extension to electron ID natural

- HBD, TRD, etc?
- Coordination with calorimetry consortium important

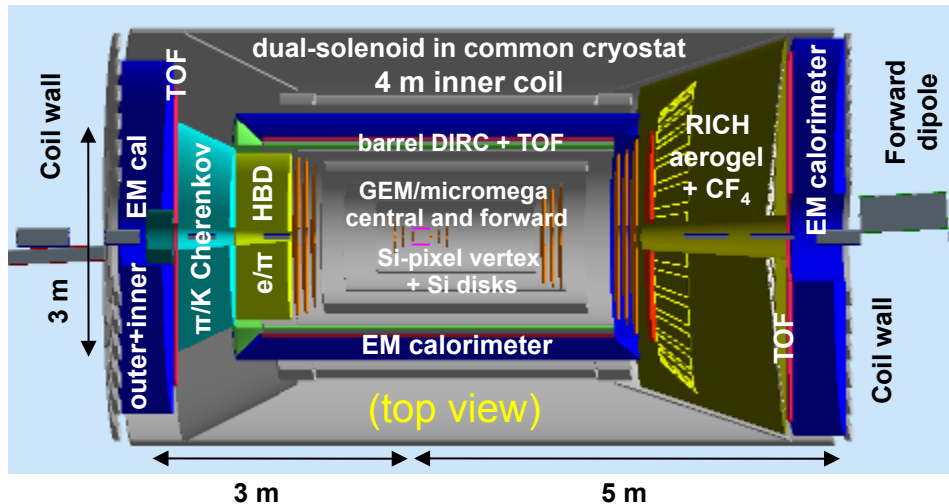**3. Formulation of requirements for other subsystems**

- Example: tracking angular resolution for DIRC/RICH
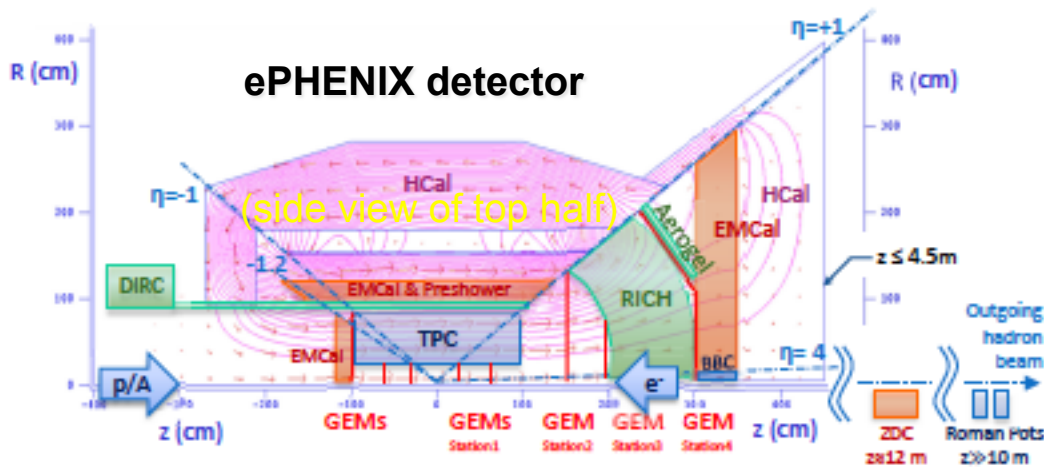
4. Increased collaboration

- Consortium mini-meeting planned for this Friday

Examples of hadron PID in EIC central detectors

MEIC IP1 detector

(top view)

(approximately to scale)

MEIC-IP1 π/K/p ID

- TOF in both endcaps and barrel
  - 10 ps relative?, ~30 ps w.r.t. RF
- DIRC in barrel (compact "camera")
- Dual-radiator RICH in hadron endcap
  - Outward-reflecting mirror
- Modular aerogel RICH in electron endcap
  - Threshold Cherenkov also possible

ePHENIX π/K/p ID

- TOF possible (endcaps and/or barrel)
  - 10 ps w.r.t. (electron only) RF?
- DIRC in barrel (long bars?)
- Gas RICH in hadron endcap
  - Inward-reflecting mirror (T. Hemmick)
- Modular aerogel RICH in hadron endcap
 - Ring along outer part of the gas RICH
- dE/dx in TPC

5

2. Time-of-Flight

Key planned R&D activities

- Continue to study performance of current 36 gap 105 µm thin glass mRPC
  - Angle, rate, position, HV, gas type dependence?
- Build and test newer mRPCs made of new dielectric materials such as 3D printed plastics, mylar, or Kapton
  - Should be able to go to > 36 gaps, and very thin gaps
  - Try to achieve 10 ps resolution
- Continue TOF/RICH/DIRC MC simulations (so far ePHENIX)
  - Improve upon physics case for TOF
  - Start looking into how detectors compare/complement each other
- Finalize Garfield++ implementation of mRPC
  - Achieve a bottom up understanding of detector performance?
- Acquire and test an Argonne 6x6 cm^2 MCP-PMT with fused silica window (mini prototype MCP-PMT TOF)
  - Also help with UV photocathode development/testing at Argonne

Contact: chiu@bnl.gov

Next steps to improve performance
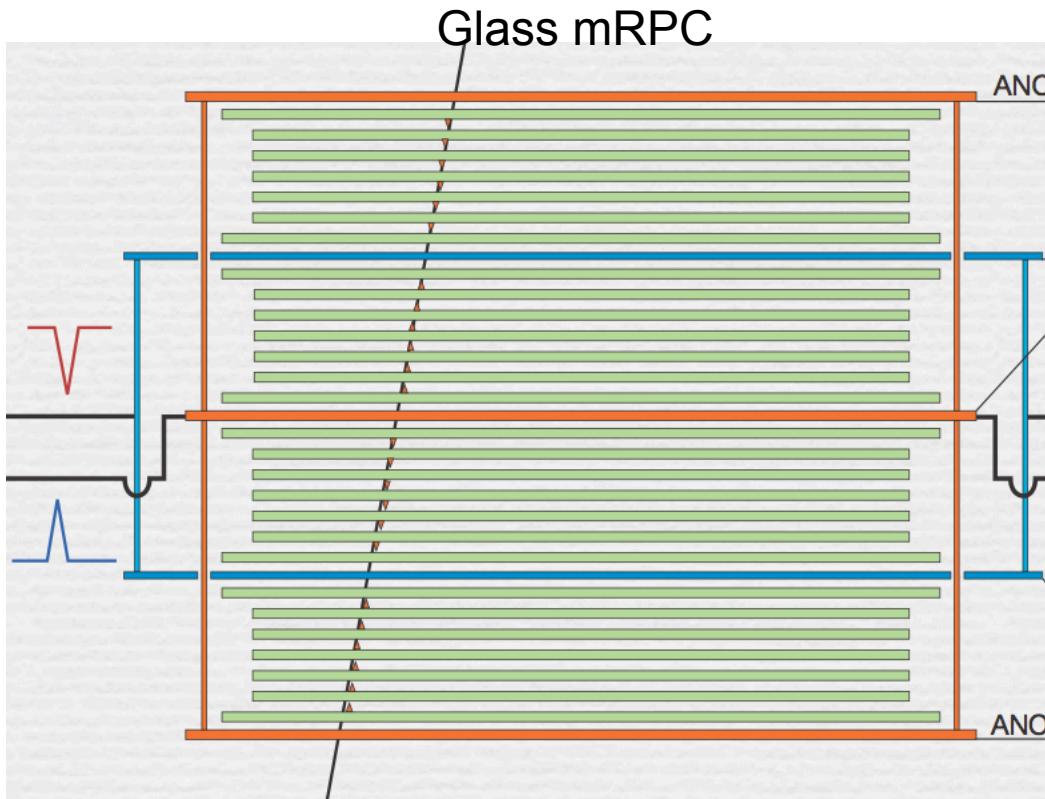

Glass mRPC

X mRPC, where X = mylar, kapton, 3D printed plastic
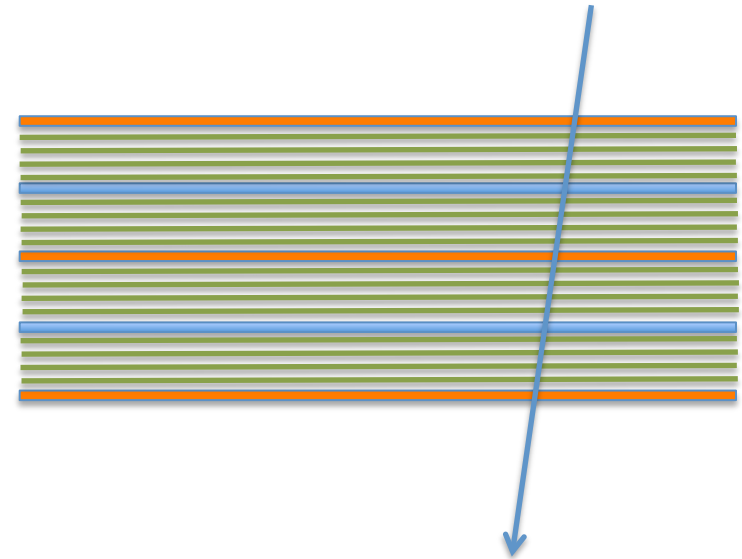
(drawn roughly to scale)

- Have achieved ~18 ps resolution with 36 105 µm gap glass mRPC
- Some ways to improve timing resolution are to
  - bring signal closer to pickup strips
  - have more gaps
- Thinner glass gets very expensive (and starts to become flexible)
- But there's a whole space of thin dielectric materials to explore!
- Just switching materials and keeping gaps same width, we should expect a much improved timing resolution (10 ps???)
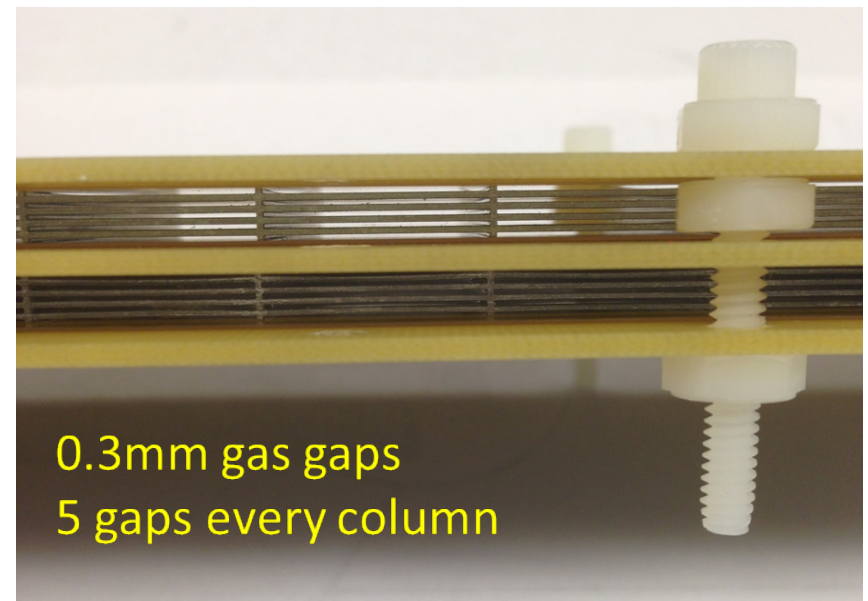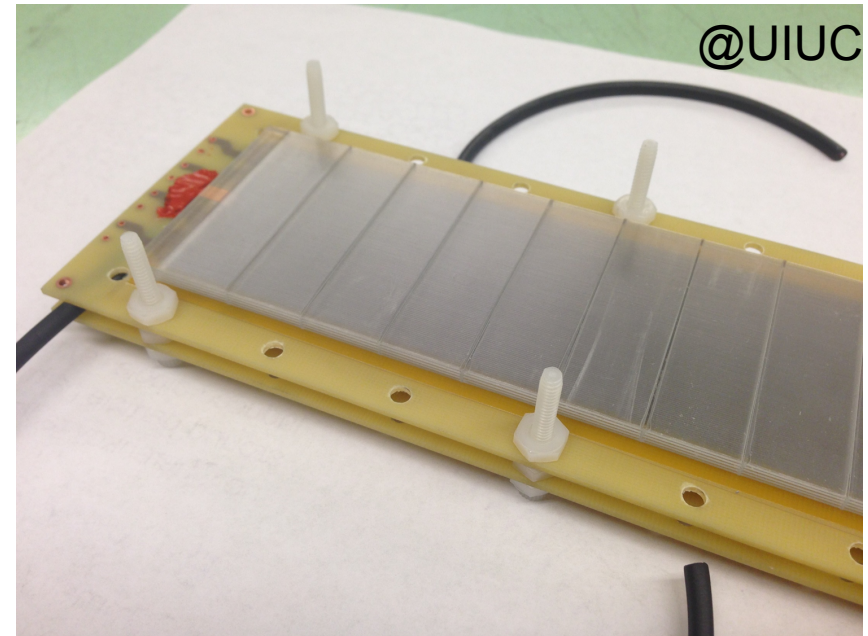
# Work already starting
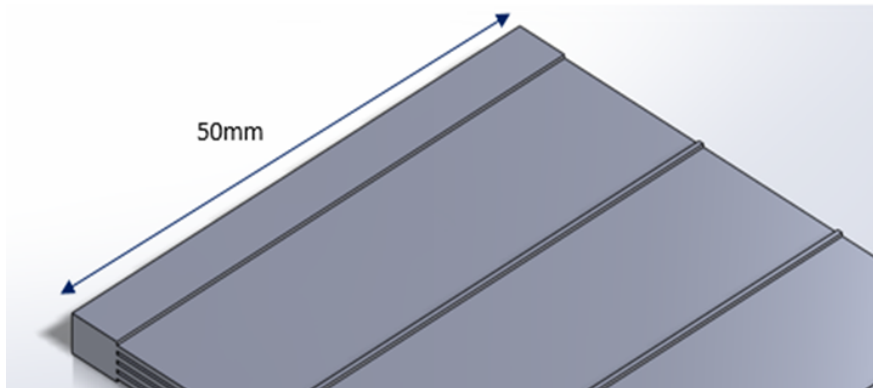
50mm

Block dimension   : 164.5mm (L) x 50mm (W) x 3.5mm (H)
Gas Gap dimension   : 15mm (L)   x 50mm (W) x 0.3mm (H/ Thickness)
Number of gas gap   : 10 horizontal x 5 vertical
Walls at two ends   : 5mm each side
Wall between gas gap (horizontal and vertical)   : 0.5mm

About $10 per piece

- Possibly very cost effective, and easy to build solution
- Will need to be careful about rate capabilities since we're using materials of very different thicknesses and resistivities compared to glass


@UIUC

0.3mm gas gaps
5 gaps every column

Also a mylar version

With HV electrodes/
signal pickup added
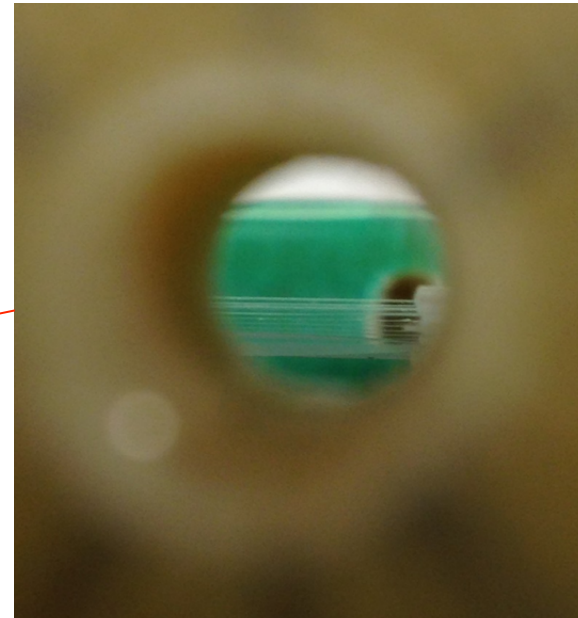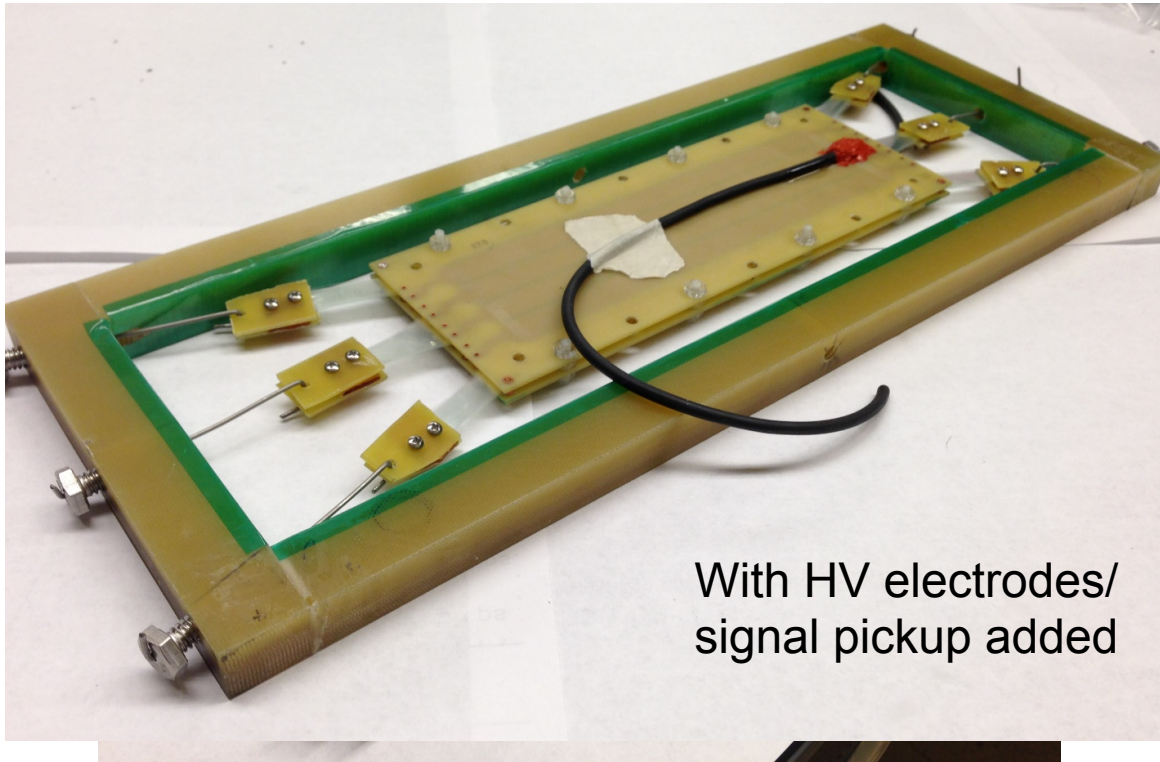
13 gaps in one stack!

- Once labs are set up, fairly easy to iterate through different configurations
    - UIUC up and running, BNL close behind, ACU and Howard will ramp up over next year
- Huge phase space to explore…
- But we think extremely good performance (~10 ps) at ridiculously low cost should be possible
- We expect the coming year to be very interesting for mRPC TOF

MCP-PMT TOF Prototype
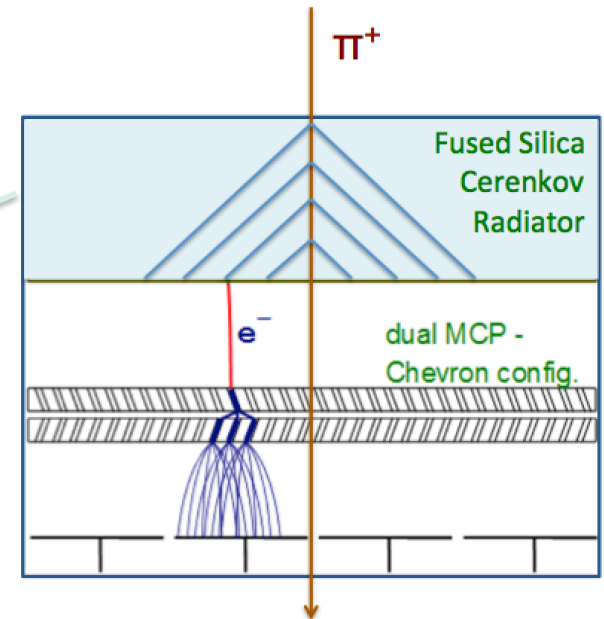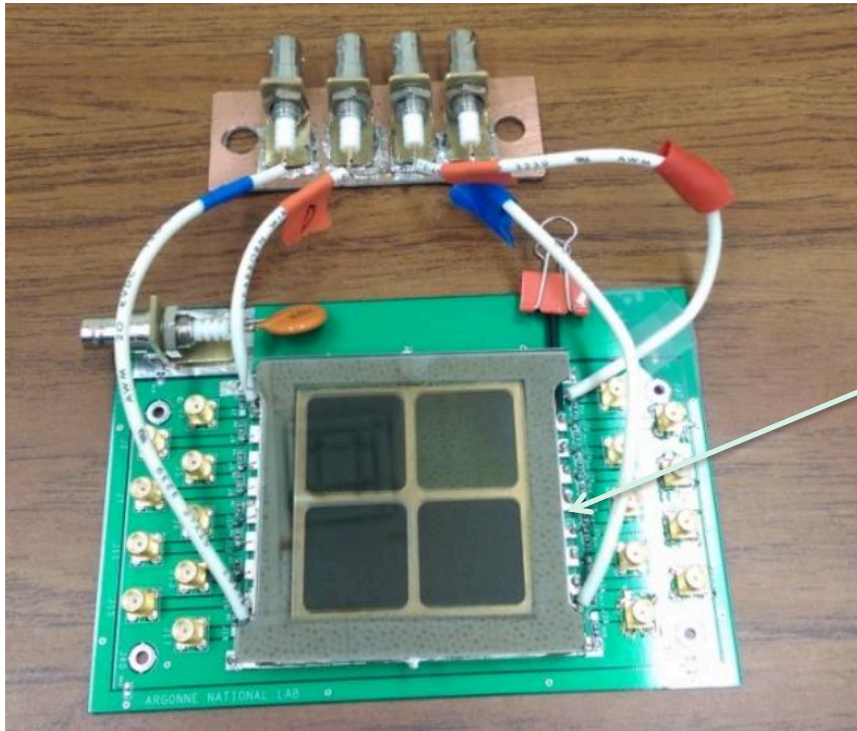
- After development of UV sensitive MCP-PMT with thin fused silica window from Argonne is successful, would like to produce and test a couple of TOF prototypes with 1 cm Cerenkov radiator in FY16
- With the expected gain in N.P.E. might be able to reach ~5 ps resolution?
- Allows more groups to work with and test LAPPD style MCP-PMTs
  - LAPPD R&D effort needs more people involved to help study rate capabilities, QE, uniformity, radiation resistance, aging effects.

3. RICH for π/K/p ID in the detector endcap(s)

Key planned R&D activities

- Continue Monte Carlo Studies
  - Implement detector options, quantify and compare performance
    - Modular aerogel imager (focusing options: lens or proximity)
    - Dual-radiator designs (focusing options: mirror or proximity)
  - Geant4 simulation and analysis in EIC environment
    - Spectrum, multiplicity, and detector backgrounds
    - In reference to designs of MEIC concept, BeAST, ePHENIX, eSTAR

- Build and test small prototype for modular aerogel imager

- Develop new GEM-based optical readout (funding postponed in FY15)
  - Start work on GaAs, GaAsP photocathodes
  - Sensitive in 300-500 nm (for modular aerogel imager)

Contact: hubert@lanl.gov

Simulation Studies – Modular aerogel imager

Continuation of the funded study under eRD11
- Implementation of lens-focused modular design in Geant4
- Pattern recognition and PID analysis packages
- Installation into a generic EIC detector (MEIC detector implementation demonstrated)
- Quantify performance in EIC environment and optimize
- Quantify requirement for aerogel, photon sensor and full spectrometer design
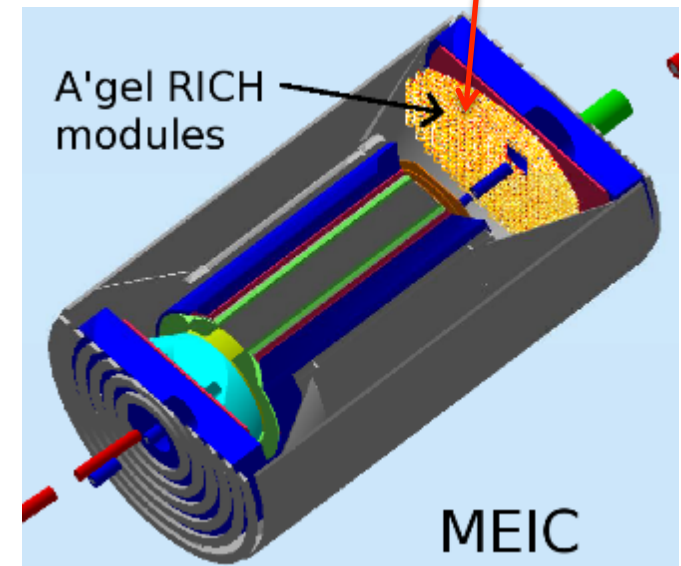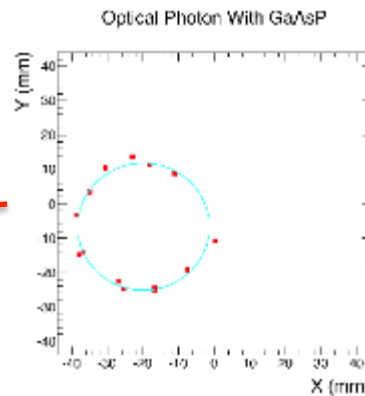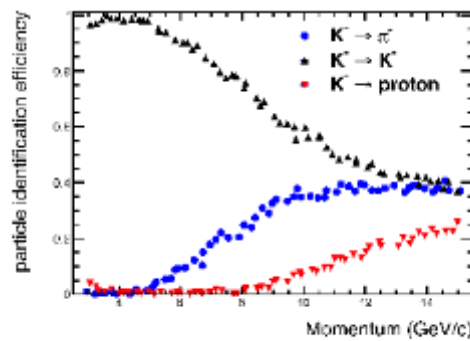- Swap and study the proximity focusing design
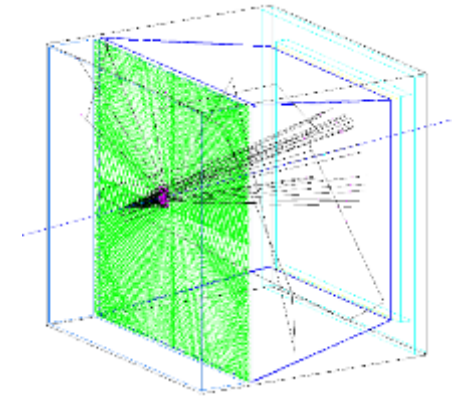
- Done
- Plan

Figure 18: Theta 5 Phi 45

Simulation studies – dual radiator designs

R&D Goal: π/K/p identification in the 2-50 GeV/c momentum range

Recently initiated under eRD11 by Dr. Alessio Deldotto (INFN) with funding through Jlab-INFN
Propose to ramp up effort in FY16-18

- Concept design and PID efficiency for proximity focusing RICH
- Concept design and PID efficiency for mirror focused RICH
- Implementation in Geant4 simulation and interface to our analysis package
- Performance quantification in full EIC detector simulation

Example geometry option to be quantified

- On-going
- Plan

13
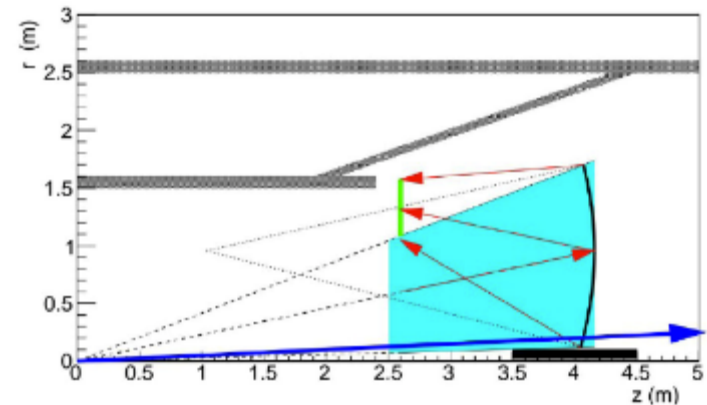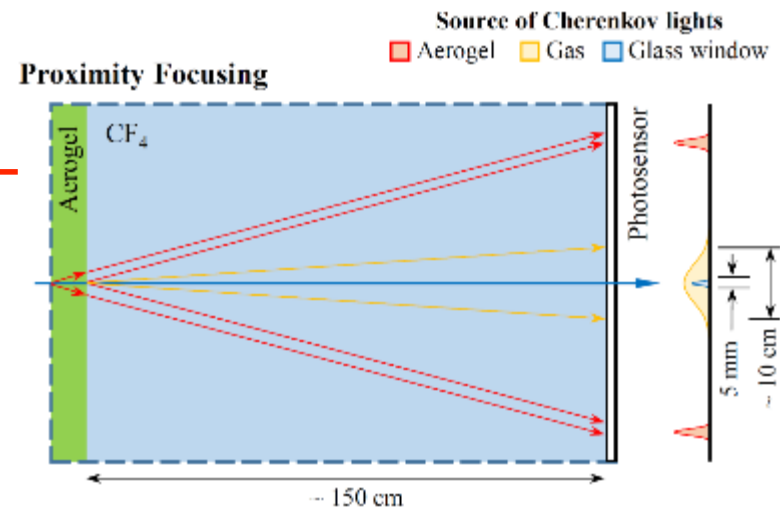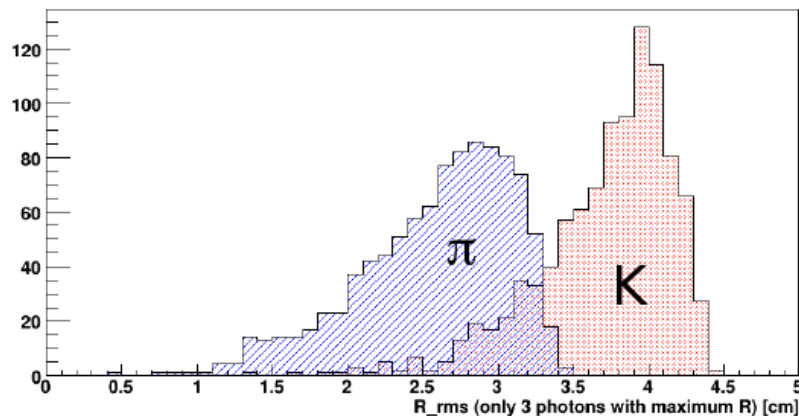
Prototype for modular aerogel RICH

A prototype can validate the ongoing MC studies, in particular of the modular aerogel imaging counter.

- Start with aerogel, fresnel lens, mirrors
- For now, use multi-anode PMT in the focal plane
- Study optical efficiency, various geometries
- Items can be checked in a cosmic ray stand, with a silicon telescope we have.
- FNAL test beam in April 2016, in conjunction with sPHENIX calorimeter test.
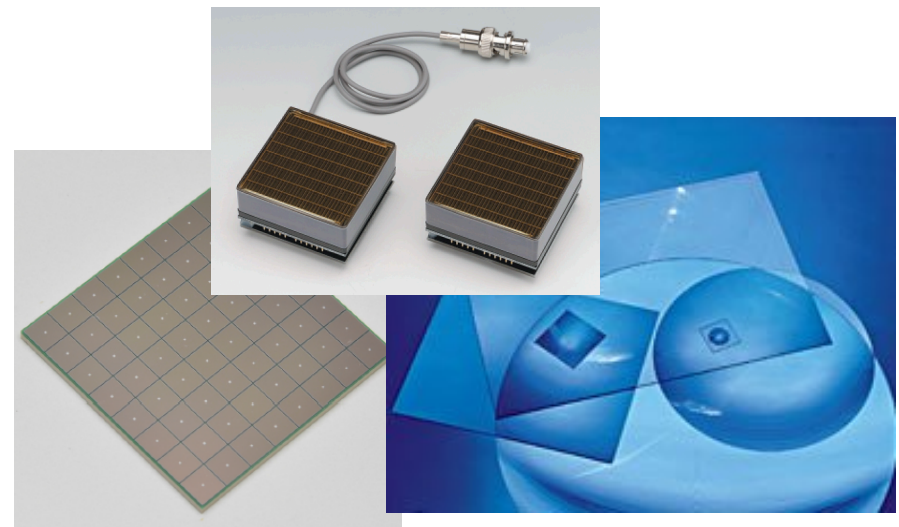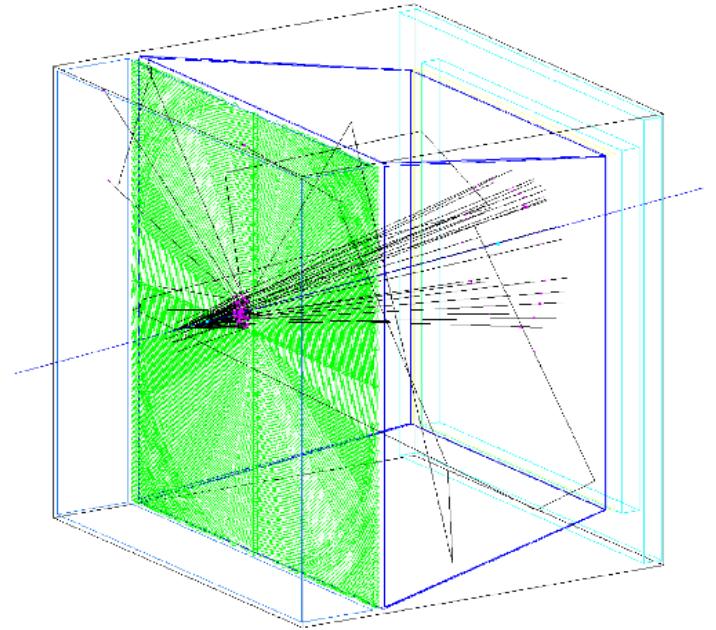
- Aerogel (HvH has samples)
- Fresnel lens: Edmund Optics 6.7" square, f=3"
- Hamamatsu multi-anode PMT (H12700A)
- Or Hamamatsu MPPC arrays, S13361 series

GEM-based optical readout

In an aerogel-based RICH, UV Cherenkov photons are (Rayleigh) scattered, so optical readout in 300-600 nm wavelength range needs to be developed.

- Start with known CsI-GEM expertise (PHENIX HBD) and technology
- Work with UNM, Center for High-tech Materials
- Study GaAs, GaAsP, in vacuum, in gas
- Deposit on GEM stack
- Optimize spectral response, given aerogel, lens and mirror optical properties properties
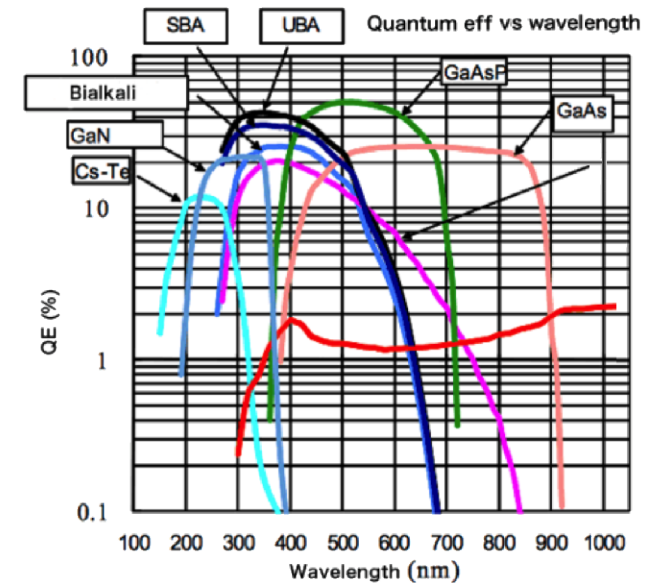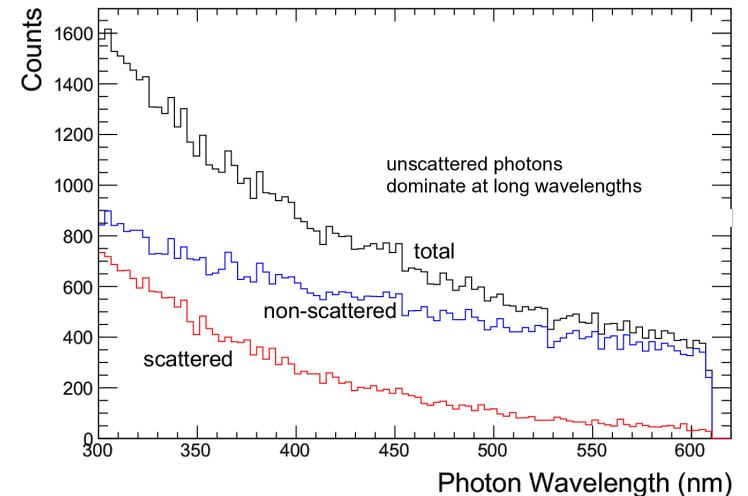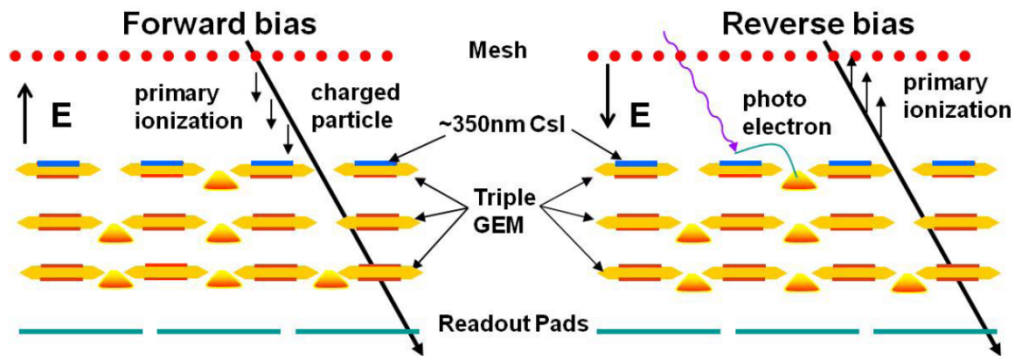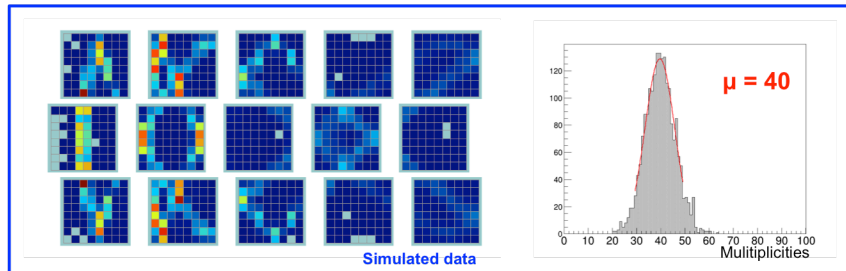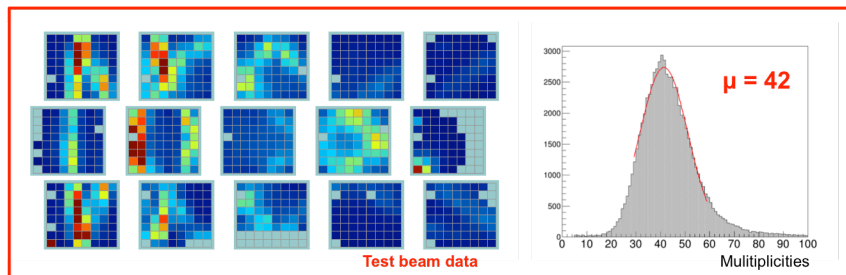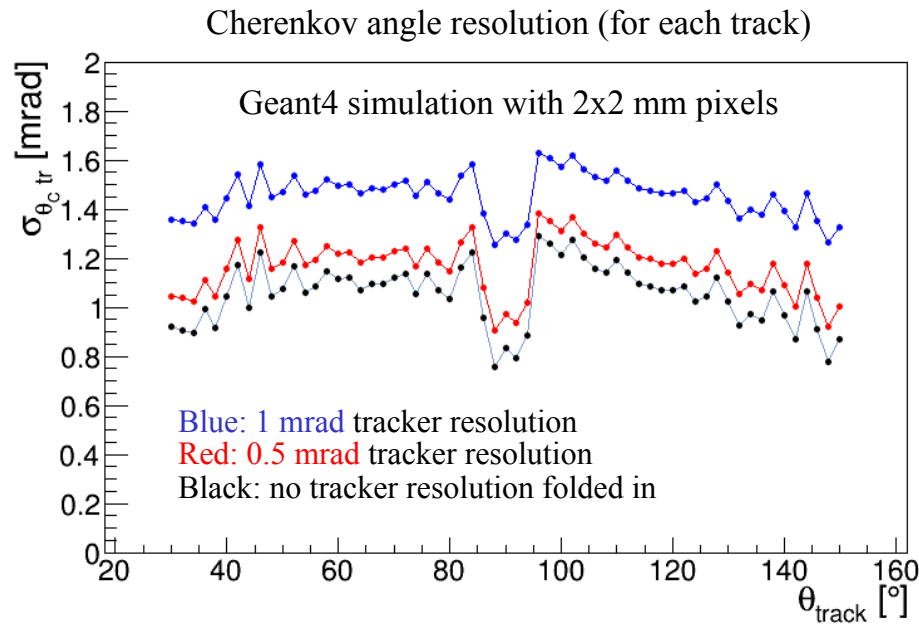
4.1 DIRC for e/π/K/p ID in the central detector

Key planned R&D activities

- Analysis of CERN 2015 test beam data
    - Validation of lens-based high-performance DIRC optics (incl. kaleidoscopic effect)

- Develop radiation-hard spherical lens
    - Also test rad. hardness of current NLaK-based lens

- Study plates as a cost-effective alternative to narrow radiator bars
    - Investigate optics and reconstruction algorithms
    - Synergies with PANDA DIRC R&D

- Study FDIRC-like mirror-based expansion volume options
    - Include options where bars are attached directly to EV and pixels are smaller
    - Synergies with GlueX DIRC construction

Contact: turonski@jlab.org

Validation of high-performance DIRC simulations

Cherenkov angle resolution (for each track)

Geant4 simulation with 2x2 mm pixels

Blue: 1 mrad tracker resolution
Red: 0.5 mrad tracker resolution
Black: no tracker resolution folded in

Test beam data

μ = 42

Simulated data

μ = 40

Beam incident at 125°

- A major milestone was achieved in FY15 with the simulation, design and in-beam test of a compact readout "camera" with optical properties demonstrating the feasibility of building a high-performance DIRC.

- While some details differed between the prototype and design of the EIC DIRC (*e.g.*, pixel size), the same Geant4 and ray-tracing (drcprop) simulations were used.

- Finishing the analysis of the GSI 2014 and CERN 2015 data is thus essential for a final validation of the simulations and performance estimates for a lens-based high-performance EIC DIRC.

Radiation hard lenses

Fused silica

N-LaK33
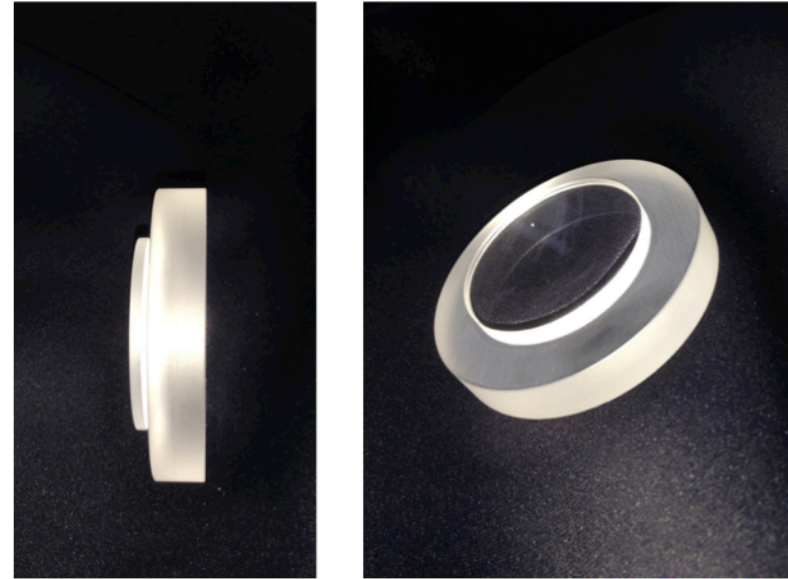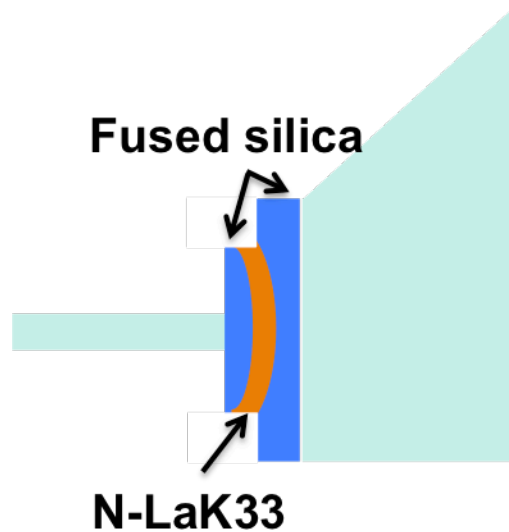
- The advanced 3-layer prototype lens developed to evaluate the optical properties of high-performance DIRC used NLaK glass, which is only moderately radiation hard.
  - Destructive radiation studies will be performed with this lens in early FY16.

- A radiation hard lens will be developed in FY17 and tested in FY18.
  - Options for the middle layer are PbF_2 or rad. hard glass
  - The latter also acts as a wavelength filter (with a cutoff in the transmission in the UV).

- The R&D will address both the mechanical and optical properties of such a lens.

18

# Plates – a cost effective alternative to bars
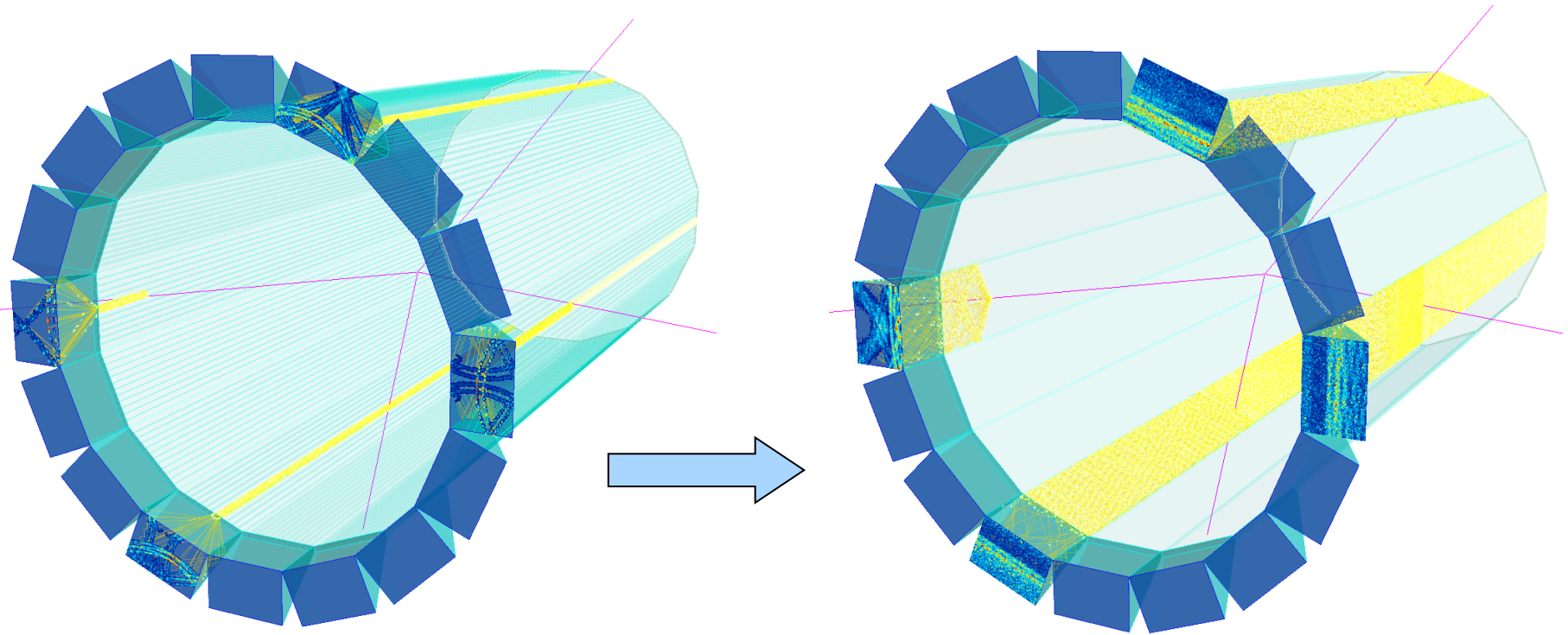
Narrow, BaBar-like radiator bars in boxes with a common expansion volume

Wide, Belle-II-like radiator plates, but coupled to a full-size spatial imager

- Plates require much fewer side reflections and can thus be made to lower tolerances.
  - Very significant cost reduction.

- R&D question: can we build a plate-based high-performance DIRC by combining time-based reconstruction (a la Belle II) with high-resolution spatial imaging?
  - Studies of azimuthal segmentation requirements at an EIC already in progress.

Focusing-mirror optics
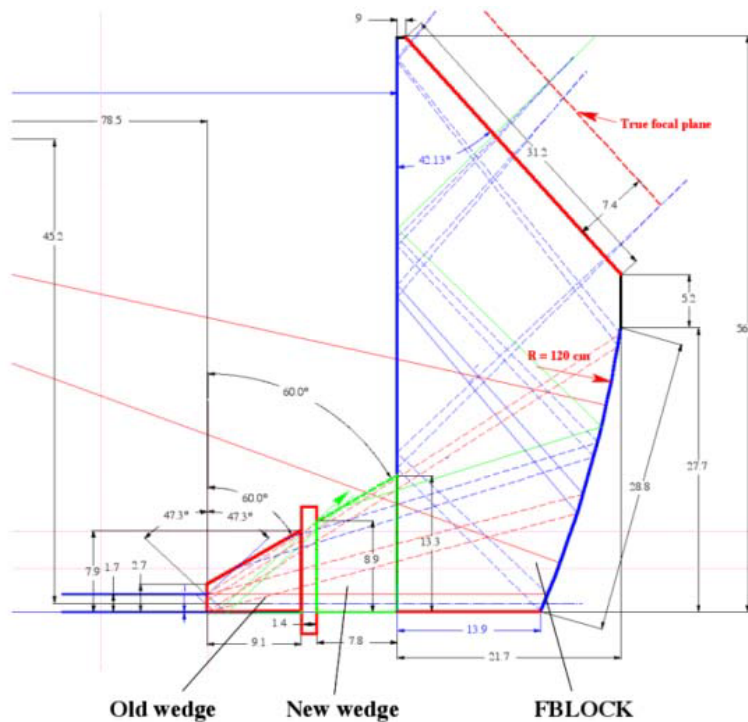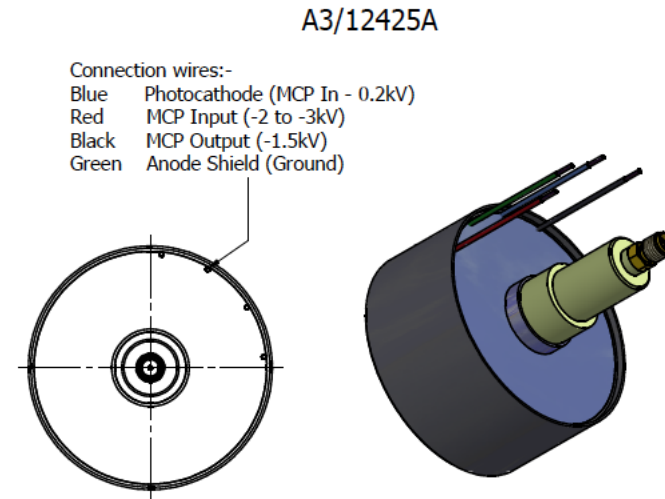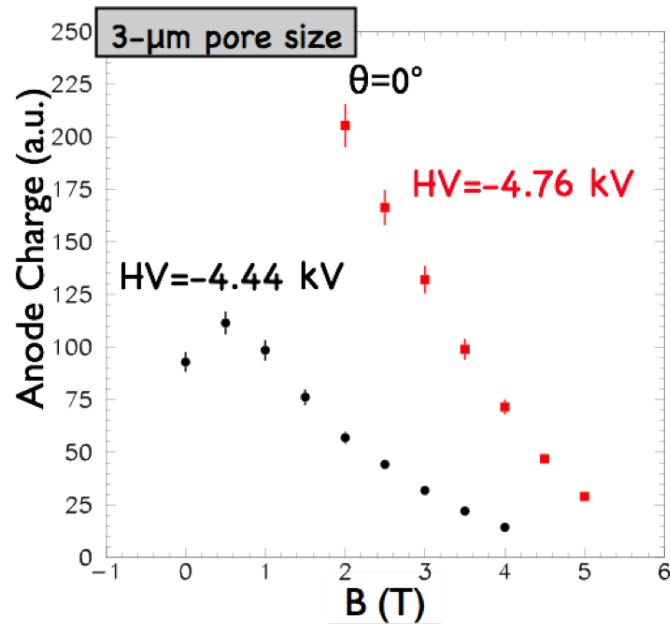

SuperB EV in drcprop
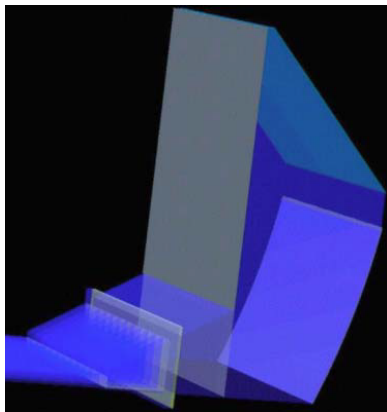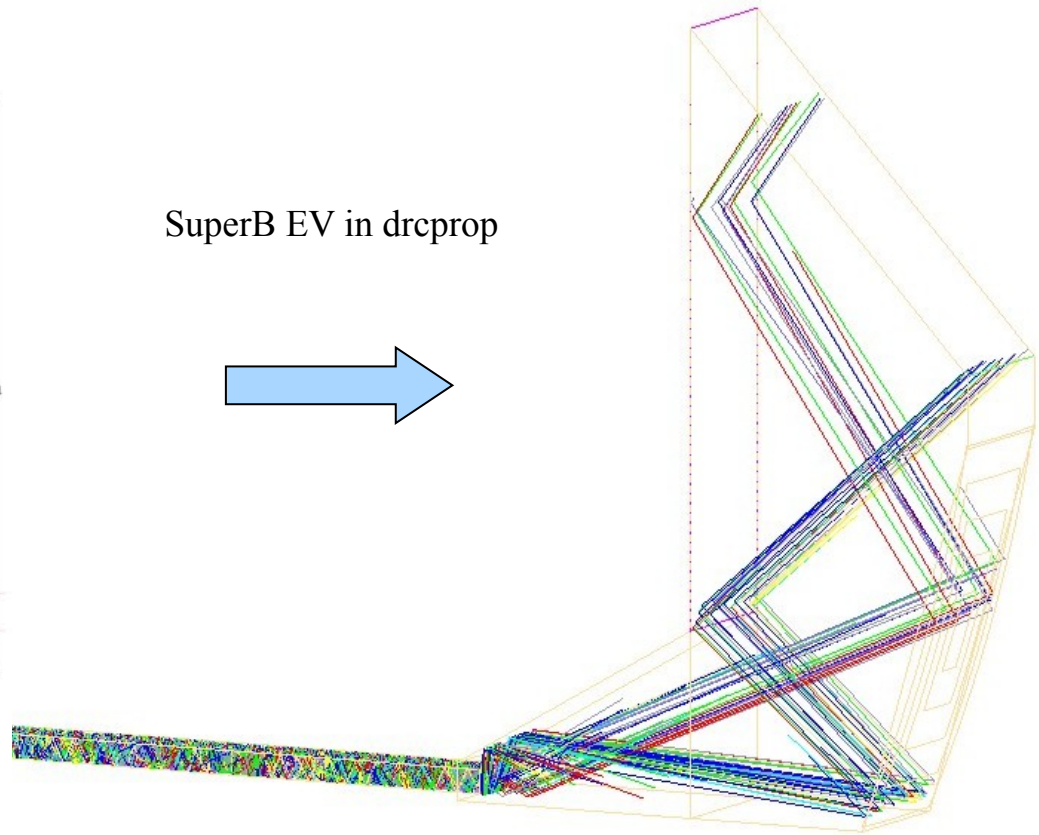
- As requested by the committee, an evaluation will also be made of a mirror-based readout instead of a lens-based one.

- Configurations with and without the performance degrading prisms of the existing BaBar bars will be studied.

- Synergies with GlueX DIRC development and construction!
  - Coordination of timelines important

20

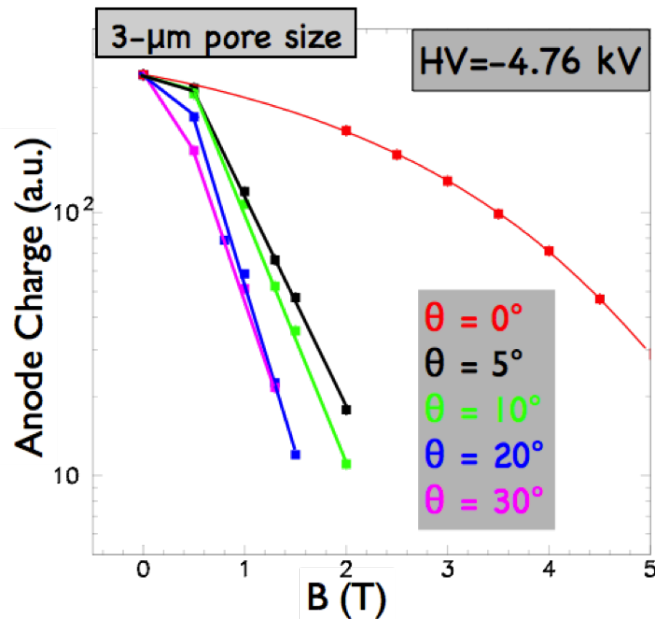# 4.2 DIRC – sensors in high magnetic fields

Key planned R&D activities

- Continue gain test program of different sensors
  - Evaluate impact of pore size, L/D ratio, MCP channel angle, etc

- Initiate MCP simulations to establish optimal parameters
  - Will use test data as input

- Start tests of impact of magnetic fields on precision timing
  - Test facility upgrade in FY18

Contact: jordanka@jlab.org

Upcoming sensor tests and planned MCP simulations

3-μm pore size
θ=0°
HV=−4.76 kV
HV=−4.44 kV

3-μm pore size
HV=−4.76 kV
θ = 0°
θ = 5°
θ = 10°
θ = 20°
θ = 30°

A3/12425A

Connection wires:-
Blue   Photocathode (MCP In - 0.2kV)
Red   MCP Input (-2 to -3kV)
Black   MCP Output (-1.5kV)
Green   Anode Shield (Ground)

Photek MCP-PMT with 3 μm pore size with modified HV

- The next series of measurements will study the impact of individually applied HVs.

- For this measurement, Photek has modified a previously measured tube

- All results from these and other measurements will be used as input for simulations at USC aimed at optimize parameters for reduced sensitivity to the B-field angle
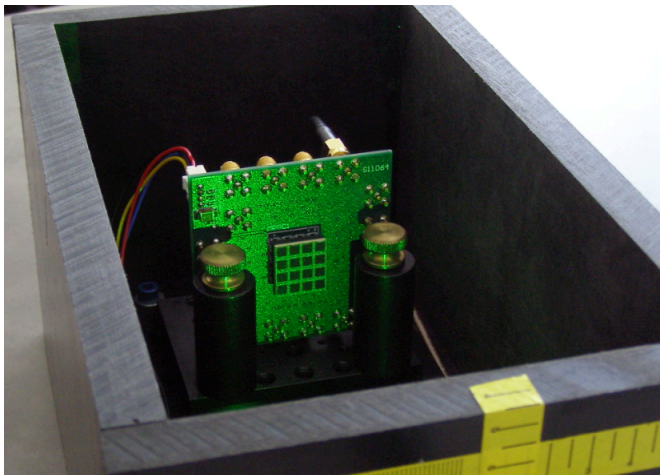
Future sensor tests

Photonis Planacon multi-pixel MCP-PMTs

Katod single-anode MCP-PMTs. Two have been procured for the EIC R&D, with 3 and 5 μm pore size, respectively

Non-magnetic dark box with pulsed LED for the DVCS solenoid – note the GlueX SiPM (Hamamatsu S11064-050P(X))

- The tests will also include the Katod MCP-PMTs procured for the EIC R&D, and tubes on loan from Hamamatsu and Photonis

- In the future, LAPPDs with pixelated readout could also be tested at the high-B facility

23

5. Sensors: LAPPD MCP-PMTs

Key planned R&D activities

- Continue performance characterization of base Argonne MCP-PMTs
  - High B-field tests at UVa or possibly Argonne
  - Tests of QE, uniformity, radiation hardness, etc.

- Work on UV-sensitive photocathodes
  - Swap in fused silica window and keep standard K_2CsSb photocathode
  - If that doesn't improve N.P.E., try Na2KSb (should result in a factor 2 improvement)

- Develop pixelated readout (FY17)
  - Two options: resistive anode or sealing PCB

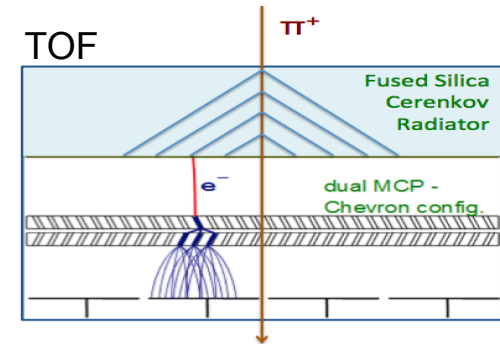Contacts: chiu@bnl.gov, zorn@jlab.org

LAPPD MCP-PMT R&D

Large area, high performance, and cost effective*, LAPPD
MCP-PMT's would be useful in many of the PID detectors
(and have been proposed).

- **Time-of-flight detectors**
  Possibly enables exquisite performance (<10 ps) over
  large areas
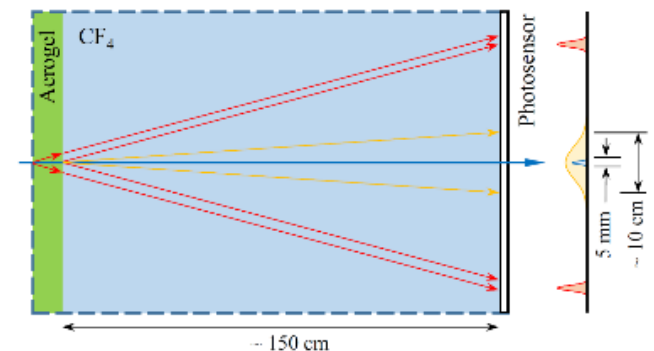 Simple to operate (just phototubes)

- **Proximity Focused RICH**
  Readout resolution: Probably a few mm resolution
  possible in pixelated version
  Timing capabilities will reduce backgrounds from non-
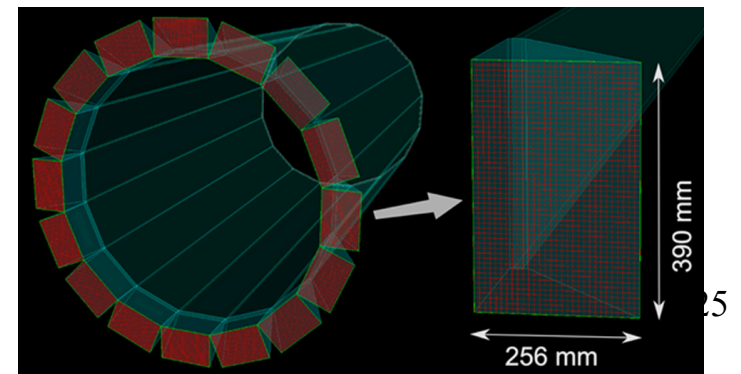 associated hits
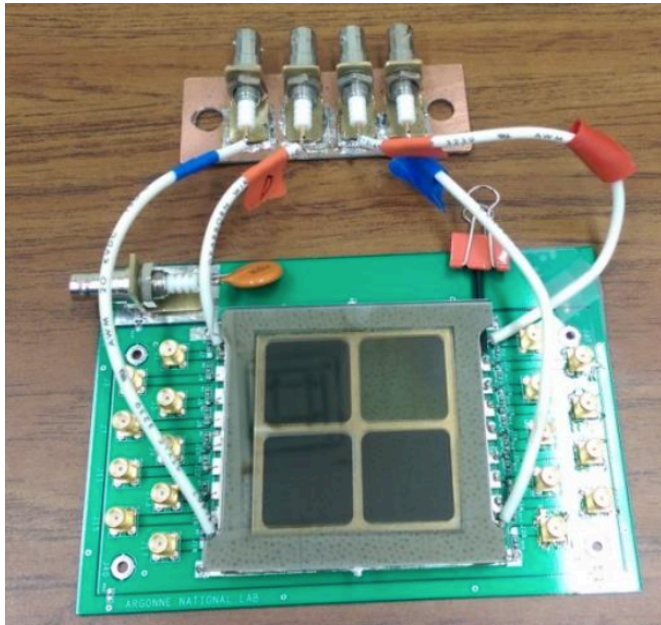 Enables limited TOF capability for PID

- **DIRC**
  Timing capabilities (~50 ps TTS) would enable DIRC to
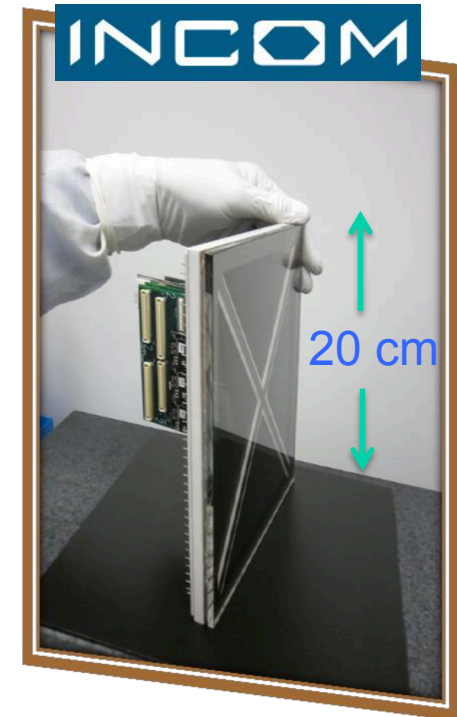 reduce large chromatic dispersion effects (i.e. TOP)

*Note that cost expected to be reduced by ~order of magnitude with
LAPPD MCP-PMTs

TOF

Proximity Focused RICH

DIRC

Leverage Argonne R&D facility

← 6 cm →

INCOM

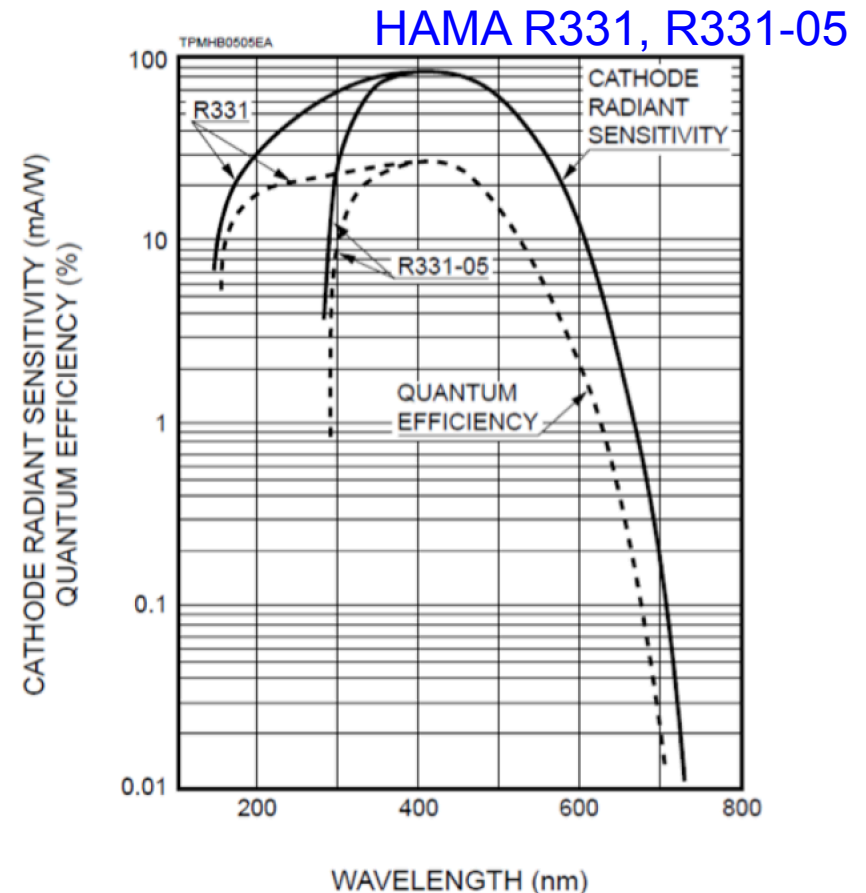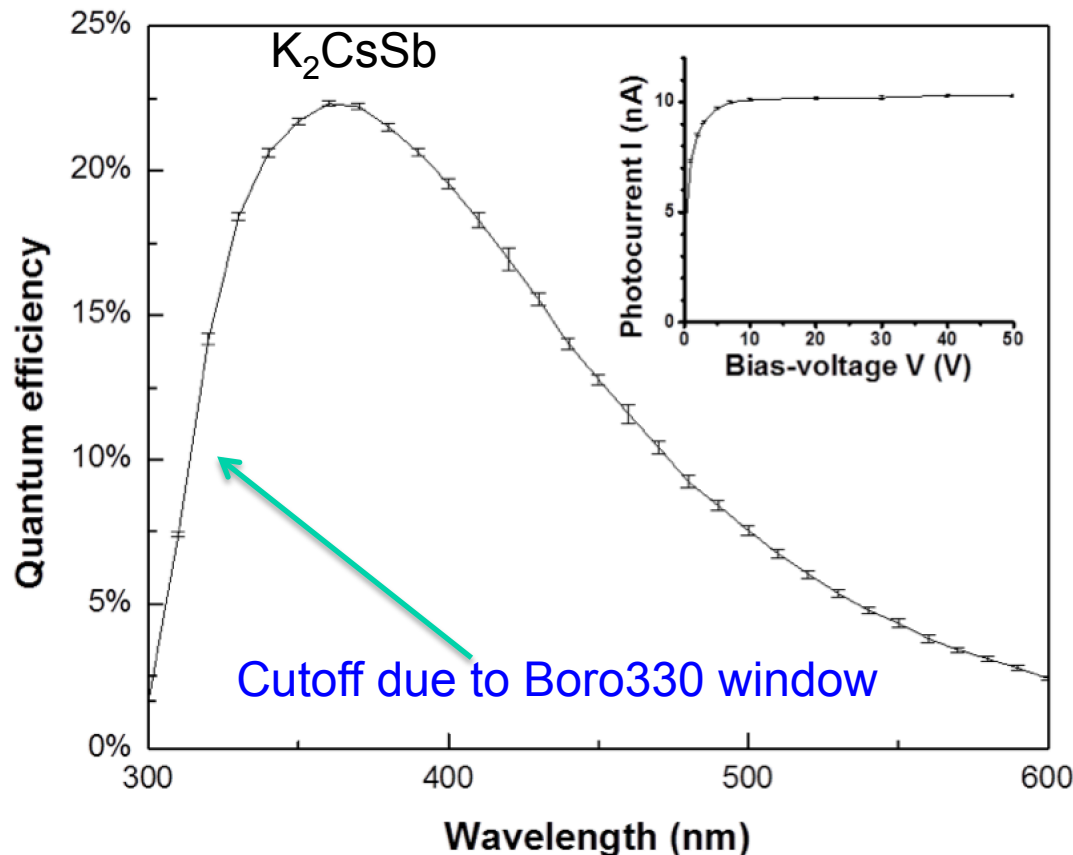20 cm
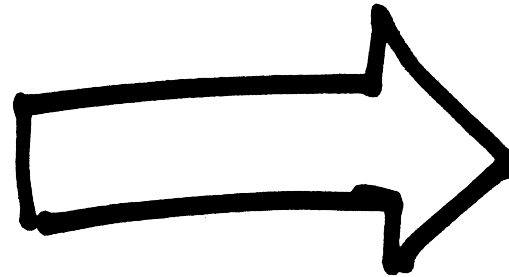
Argonne Tile Facility is ideal place to develop and test improved designs of the LAPPD MCP-PMT.

These improvements can then be incorporated into the commercially produced (and cheaper) MCP-PMTs by Incom, Inc.

26

UV-sensitive photocathode

- Possibly simple modification that would increase N.P.E. by a factor of ~2 would be to replace the borosilicate window with fused silica (similar to improvement for Hama R331/R331-05)
  - Factors of 2 would be great improvements for EIC detectors which are currently pushing the limits of performance
- Some controversy over K_2CsSb QE at wavelengths < 300 nm
  - In case N.P.E. not improved, try Na_2KSb, which should have a broad QE curve

Pixelated readout for LAPPD MCP-PMT
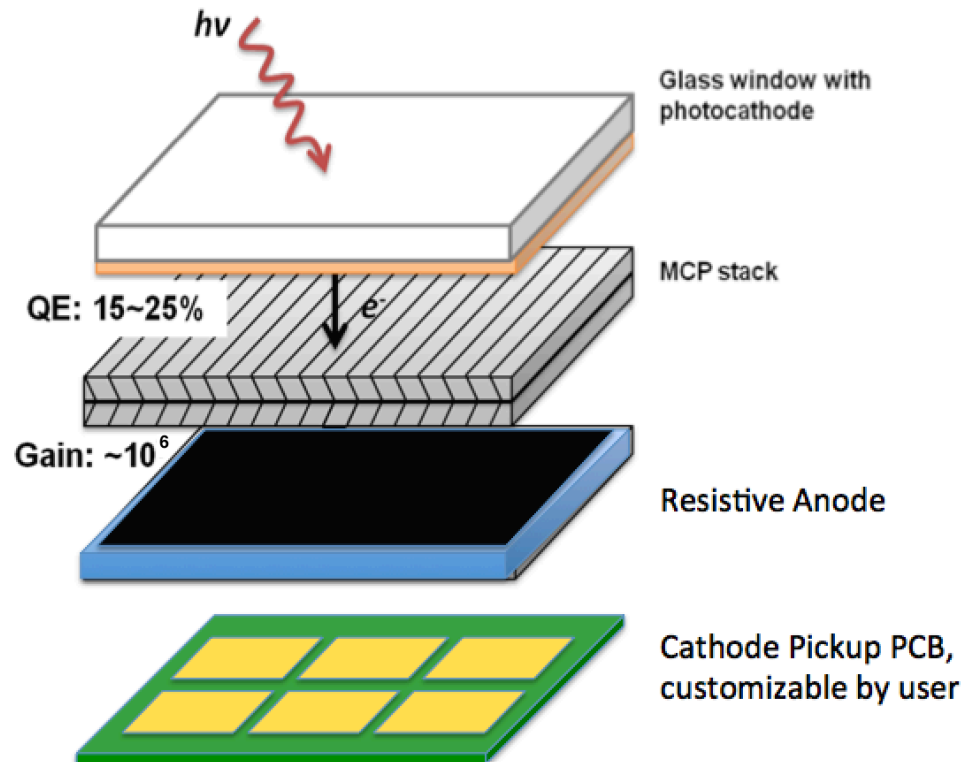
- Pixelated readout at the ~2-4 mm resolution level is required for DIRC and RICH detectors
- Currently not being worked on in the LAPPD collaboration
- More technically challenging than the UV sensitive photocathode work

Budget Request (including overheads)

Budget by chapter/activity

	FY16	FY17	FY18	Total
TOF	$63k	$6k	$3k	$72k
RICH	$226k	$201k	$189k	$616k
DIRC + high-B	$115k	$147k	$147k	$409k
LAPPDs	$100k	$90k	$60k	$250k
Total	$504k	$444k	$399k	$1,347k

Budget by category

	FY16	FY17	FY18	Total
Prof/Staff	$37k	$62k	$37k	$136k
Postdocs	$251k	$200k	$200k	$651k
Students	$46k	$54k	$54k	$154k
Hardware	$112k	$65k	$48k	$225k
Travel	$58k	$63k	$60k	$181k
Total	$504k	$444k	$399k	$1,347k

Funds for senior personnel go to ANL (3/4) and UNM.

Postdoc funds will support domestic positions (with matching funds) at ANL, GSU, ODU, and UNM through FY16-18. The UIUC request if for FY16 only. The funds will also support a postdoc at INFN.

The student funds support students at CUA (undergraduate), GSU, USC (one undergraduate in FY16 and two in FY17-18), UNM, and UTFSM.

Budget request by institution

Budget by institution

	FY16	FY17	FY18	Total
ANL	$90k	$80k	$50k	*$220k*
BNL	$6k	$6k	$6k	*$18k*
CUA	$8k	$8k	$8k	*$24k*
Duke	$2k	$2k	$2k	*$6k*
GSU	$99k	$69k	$69k	*$237k*
INFN (JLab)	$46k	$55k	$55k	*$156k*
JLab and GSI	$41k	$61k	$61k	*$163k*
LANL	$4k	$4k	$4k	*$12k*
ODU	$55k	$55k	$55k	*$165k*
UIUC	$63k	$6k	$3k	*$72k*
UNM	$69k	$65k	$53k	*$187k*
USC	$16k	$28k	$28k	*$72k*
UTFSM (JLab)	$5k	$5k	$5k	*$15k*
Total	*$504k*	*$444k*	*$399k*	*$1,347k*

Procurement

FY16:

  $35k for construction of modular aerogel RICH prototype
  $17k items for GEM photocathode work
  $20k high-B test facility operations
  $40k items for LAPPD work

Total: $112k

FY17:

  $5k materials for modular aerogel RICH prototype
  $13k items for GEM photocathode work
  $25k radiation hard lens for high-performance DIRC
  $17 high-B test facility operations
  $5k items for LAPPD work

Total: $65k

FY18:

  $5k materials for modular aerogel RICH prototype
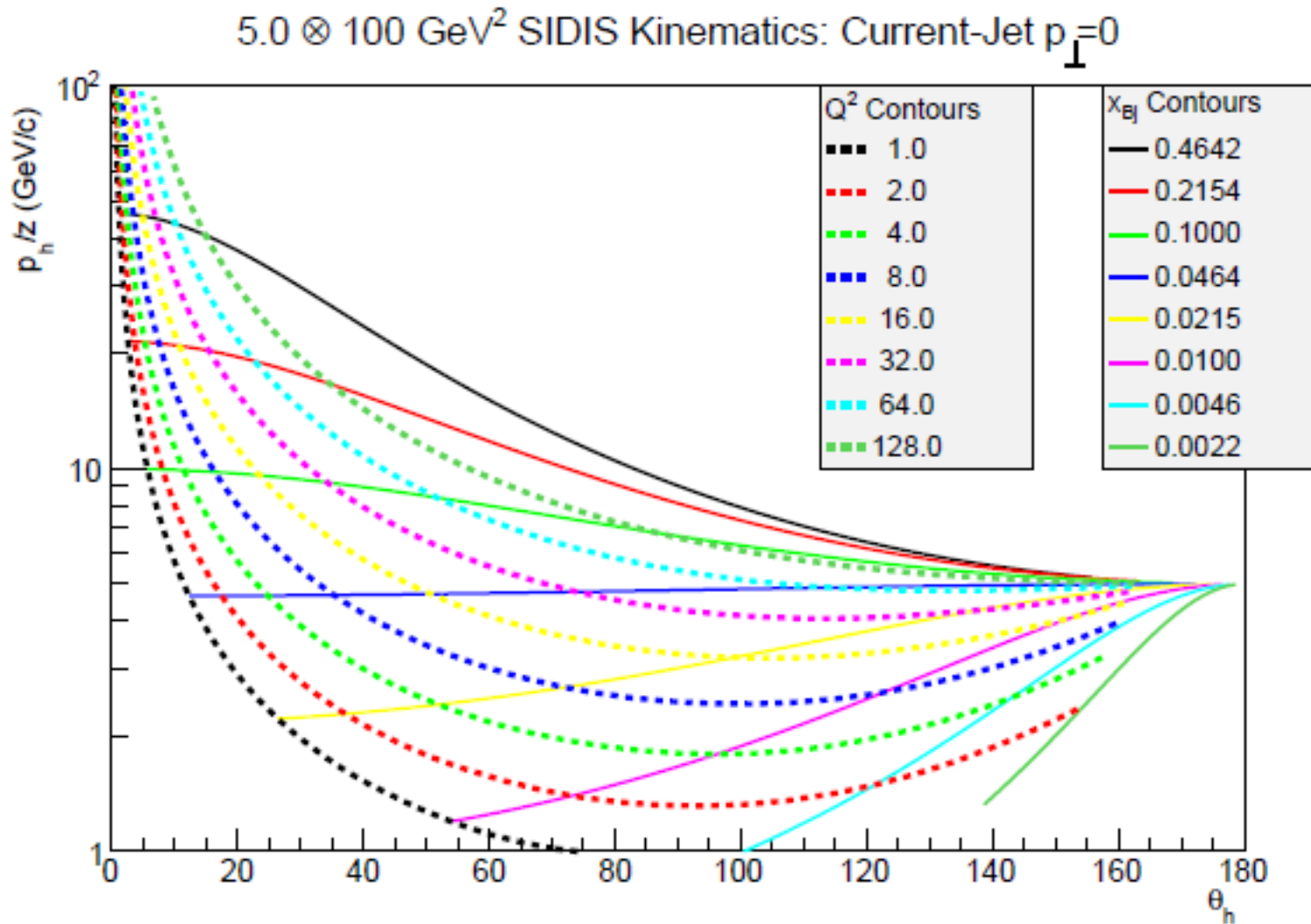 $1k items for GEM photocathode work
  $30k timing upgrade for high-B test facility
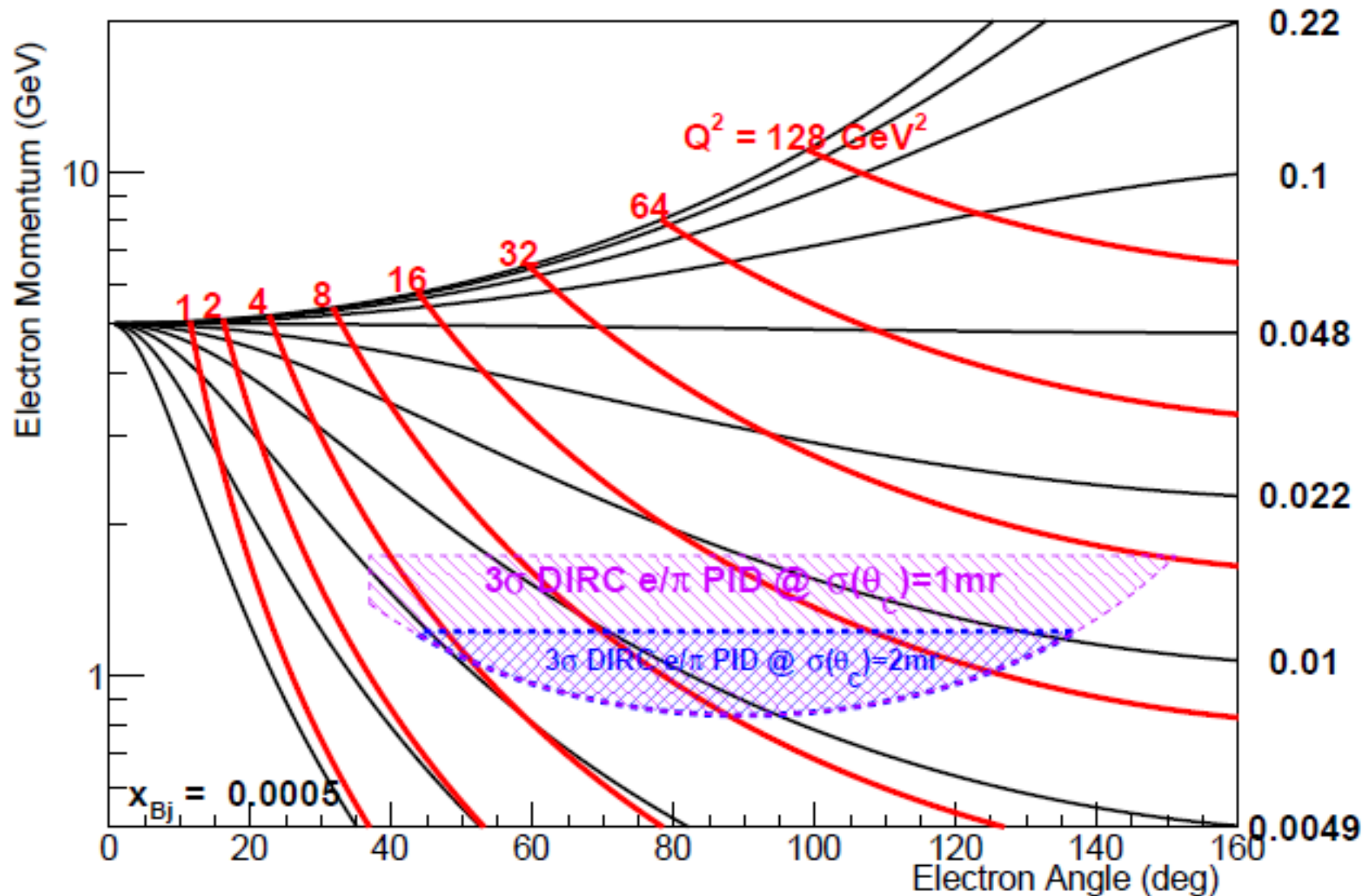 $12k high-B test facility operations

Total: $48k

Backup

Example: π/K identification in semi-inclusive DIS

- Need high momentum coverage – especially at forward barrel angles!

Example: e/π identification in DIS at low *x*

Collider Kinematics 5.0 ⊗ 100 (GeV/c)²

- High-Q^2, low-x electrons have low momenta and require good pion suppression